

# Status and Perspectives of Indirect Search for Dark Matter

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**Abstract.** I summarize here and discuss the results of presently operating neutrino telescopes in searching for a signal of dark matter weakly interacting massive particles (WIMPs).

## 1. Introduction

The status of dark matter problem is quite complicated (for a review see ref.[1, 2]) but clearly displays the close connection of the fundamental characters of the early Universe with the interaction properties of elementary particles. Existing evidence of a cosmologically significant amount of dark matter being able to explain as much as 99% of the mass of the Universe together with Big Bang Nucleosynthesis and formation of large structures in the Universe supports hypothesis of the non-baryonic and mainly cold (75%) dark matter bulk.

In a Minimal Supersymmetric Standard Model (MSSM) with R-parity conservation the lightest of the four neutralinos assumed to be stable against decay and annihilating at weak scale [3]. Thanks to that neutralino provides a relic density close to the critical one.

The opportunity for indirect signature as well as for direct detection of WIMPs is coming from a drastic assumption that WIMPs elastically interact (via mass and spin) with ordinary baryonic matter [3, 4]. Since neutralinos are a mixture of the respective partners of the electrically neutral gauge bosons  $B$  and  $W_3$  (gaugino states) and two Higgs bosons (higgsino states), a value of the neutralino mass under demand of a grand unification [5, 6] is defined by four independent space parameters:  $m_0, m_{1/2}, A_t, \tan\beta$  and also  $\text{sgn}(\mu)$  in its conventional means. The experimental lower mass

limits have been set by large accelerators [7] ( $> 25.9\text{eV}$ ), while an upper mass limit is assumed to be in TeV range respectively to a suggestion about neutralino cosmological abundance.

The underground neutrino telescopes have measured in global an order of three thousands of the muonic neutrino events from down hemisphere. Statistics allows to look for an excess of upward-going muons relatively to the expectations from atmospheric neutrinos in the directions of the Sun and near the centre of the Earth, while these astrophysical bodies could be considered as energetic neutrino sources. Accordingly to the theory in the solar system the capture rates of neutralinos by the Sun and the Earth are enough large to provide a thermal equilibrium with the annihilation rate at the scale of the Universe age [8] inside its central regions where neutralinos might get accumulated due to crossing gravitationally trapped orbits [4, 9] and subsequent energy losses via elastical scattering [10]. Decays of generated fermions and bosons in neutralino annihilation channels produce high energy leptons from which only neutrinos survive on the way to the detector.

Presently neutrino experiments of the Baksan [11] and MACRO [12] following IMB [13] and Kamiokande [14] researches of dark matter WIMPs have set a more stronger muon flux limits at the 90% confidential level (c.l.), since they did not measure significant excess of upgoing muon events in the direction of the pointed out predicted neutralino sources.

As it has been shown [23], a detector with an area of  $\text{km}^2$  running for one year would be sensitive to a few TeV range of neutralino masses. The first results from Baikal [15, 16] and AMANDA [17, 18] as well as demonstrator of ANTARES project [19] presenting principally new generation of neutrino detectors offer having more sensitive instruments for indirect searching for WIPMs.

## 2. General considerations of the method

The efforts in searching for neutralino indirect signature aim to differentiate the measured flux of neutrino events into expected one from neutralino sources and from atmospheric neutrinos background. The expected number of upward-going muons is defined by a fall of neutrino flux ( $dN_{\nu_j}/dE_\nu$ ) from a source at distance ( $R$ ) and by a probability ( $P_j(E_\nu)$ ) that  $j$ -th type neutrino with primary energy  $E_\nu$  will produce a muon which arrives at the detector with energy  $E_\nu$  higher than threshold  $E_{th}$ . For a remote moving source of neutrinos (as the Sun) the detector rate depends also on a track on the sky. The value  $P(E_\nu)$  is determined by second momentum of the  $E_\nu$ , because of the  $\nu_\mu N$  cross section and muon path range increase with neutrino energy. The spectrum of atmospheric  $\nu_\mu$ -background is a

decreasing  $E^{-3}$  function of  $\nu$ -energy. Hence, for a more energetic muons it is more advantageously to look for a DM signal from predicted neutrino sources, including the Earth core and the Sun. Due to the neutralino mass value which allows to have one order magnitude difference, the generated neutrino fluxes from decay processes of neutralino annihilation products will be characterized by different hardness of spectrum respectively to a branching ratios ( $B_i$ ) into annihilation channels:

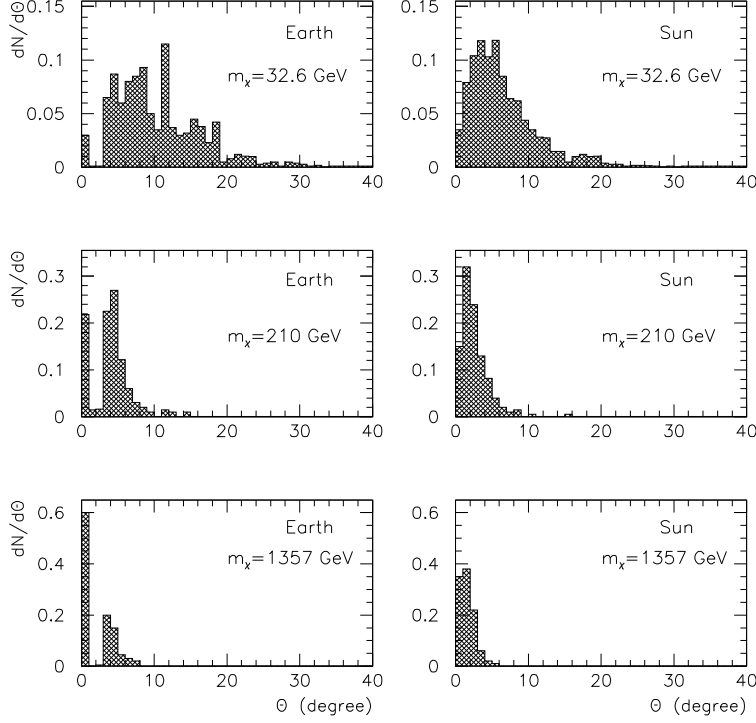
$$\frac{dN_{\nu_j}}{dE_\nu} = \frac{\Gamma_A}{4\pi R^2} \sum_i B_i \frac{dN_{\nu_j}^i}{dE_\nu}, \quad \nu_j = \nu_\mu, \bar{\nu}_\mu.$$

Here  $dN_{\nu_j}^i/dE_\nu$  is the differential spectrum of  $j$ -th neutrinos at the surface of the the Sun or the Earth produced in annihilations into the  $i$ -th channels. While the branching ratios are calculated accordinally to the theory of annihilation cross sections [21], the annihilation rate ( $\Gamma_A$ ) is evaluted from capture rate and is a function depending on a few astrophysical and nuclear values which are known with large uncertanties [2, 6, 10]. Notice that the Baksan collaboration has obtained [11] the 90% c.l. upper limits on annihilation rate defined to be completely detector independent and as a function of the neutralino mass. They could be directly applied to comparison with a theoretical calculations, in contrary to the limits on muon fluxes being detector depending values.

The modern telescopes do not measure neutrino spectra. So discrimination of nonatmospheric origin neutrinos from atmospheric ones is carried out on zenith angular distributions. The angular resolution is dominated for this task together with the existing detector's acceptance for different neutrino fluxes.

In the case of neutralino sources the expected signal is strongly collimated. Fig.1 shows the response of Baksan underground scintillator telescope on Monte Carlo simulated neutralino annihilations inside the Earth core and the Sun for different masses of neutralinos.

Although the distributions reflect the installation construction and depend on neutralino composition, nevertheless it seen that a more larger neutralino mass gives a more narrow shape of the distribution. Optimization of the signal to background ratio by appropriate angular selection of data on basis of signature of modeled neutralino annihilations has been done by the Kamiokande, Baksan, MACRO and AMANDA collaborations. Tables 1 and 2 summarize the results over the operating telescopes, displaying the 90% flux limits and search half-cones collecting 90% of expected neutralino signal. The angular maximum is followed to be not higher than  $25^\circ$  for the Earth and  $16^\circ$  for the Sun. Under the LEP bound [7] on neutralino mass these angular window limits are decreasing at least on  $5^\circ$ .



**Figure 1.** Zenith-angular distributions of MC simulated upward-going muons from  $\chi - \chi$  annihilations. Parameter set:  $\tan\beta = 8$ , gaugino part is 0.5, pseudo-scalar Higgs mass  $m_A=121$  GeV,  $\mu > 0$ .

### 3. Simulation models

There are a few theoretical groups [2, 22, 23] which carried out SUSY models down to an applicable neutrino spectra from neutralino annihilation for further calculation of upgoing muon fluxes at a given neutrino telescope. All of them contain a different incorporated effects related with the calculation of relic density of neutralinos, so below the authors of SUSY models will be indicated. Simulation of neutrino signal from neutralino annihilation implies calculation of neutralino space spread in the source, which is determined by local gravitational potential. With an approach of constant neutralino temperature equal to the central one, neutralinos have spaced with a shape of Gaussian distribution with inverse dependence on

**Table 1.** The 90% c.l. upper limits on upward-going muon fluxes for  $\chi\bar{\chi}$  annihilations in the Earth's core and half-cones collecting 90% of  $F_{\mu}^{ann}$

Half-cone (°)	BAKSAN		MACRO		BAIKAL		AMANDA B10	
	$m_{\chi}$	$\Phi_{\mu}^{upper}$	$m_{\chi}$	$\Phi_{\mu}^{upper}$	$\Phi_{\mu}^{upper}$	$m_{\chi}$	$\Phi_{\mu}^{hard}$	$\Phi_{\mu}^{soft}$
	(GeV)	( $10^{-14}$ $\text{cm}^{-2}\text{s}^{-1}$ )	(GeV)	( $10^{-14}$ $\text{cm}^{-2}\text{s}^{-1}$ )	( $10^{-14}$ $\text{cm}^{-2}\text{s}^{-1}$ )	(GeV)	( $10^{-14}$ $\text{cm}^{-2}\text{s}^{-1}$ )	( $10^{-14}$ $\text{cm}^{-2}\text{s}^{-1}$ )
30.0				2.01	11.0			
25.0	12.8	3.2			9.3			
24.0				1.56				
18.0	32.6	2.1		1.28	5.9 - 7.7			
15.0				1.03	4.8	100	14.1	103.8
						....		
						5000	2.1	3.4
14.8			60					
11.8			100					
10.0	82.8	0.93				100	9.8	82.2
						....		
						5000	1.3	2.1
9.0				0.658				
8.4			200					
7.0	210	0.62						
6.0			500	0.507				
5.0	535	0.54				100	23.6	231.3
4.9			1000			250	3.7	16.4
4.5	1358	0.52				500	2.3	6.2
4.0	3454	0.52				1000	1.8	3.8
3.0				0.289		5000	1.3	2.3

mass [8, 23]. While in case of the Earth predicted angular distribution of annihilation neutrinos is strongly correlated with the neutralino space distribution, inside the Sun the distribution of generation points of neutrino have to be accounted in the sense that there are energy losses both in quarks hadronization processes and in neutrino passage through a high density layers of the Sun resulting to neutrino spectrum modification [24]. The neutrino's yield ( $dN_{\nu_j}^i/dE_{\nu}$ ) is evaluating on basis of inclusive neutrino spectra arising in simulations of  $e^+e^-$  annihilations according to PYTHIA versions and with applying of two-body decay kinematics to boson and t-quark channels of neutralino annihilations (see for review [2]). Monte Carlo simulation of neutrino signal at the detector subdivides in two parts. At first one, neutrino interactions with the matter surrounding the detector and muon propagation up to the detector are modeling. Neutrino flux being calculated in dependence on model (atmospheric origin or neutralino

**Table 2.** The 90% c.l. upper limits on upward-going muon fluxes for  $\chi\bar{\chi}$  annihilations in the Sun and half-cones collecting 90% of  $F_{\mu}^{ann}$

Half-cone ( $^{\circ}$ )	BAKSAN		MACRO	
	$m_{\chi}$ (GeV)	$\Phi_{\mu}^{upper}$ ( $10^{-14}$ $\text{cm}^{-2}\text{s}^{-1}$ )	$m_{\chi}$ (GeV)	$\Phi_{\mu}^{upper}$ ( $10^{-14}$ $\text{cm}^{-2}\text{s}^{-1}$ )
30.0				6.38
24.0				4.06
18.0				2.77
16.0	12.8	2.4		
15.0				2.07
13.0	32.6	2.1		
12.9			60	
10.3			100	
9.0				1.42
7.5			200	
6.5	82.8	1.1		
6.2			500	
6.0				1.07
5.8			1000	
4.7	210	0.65		
3.6	535	0.64		
3.0	1358	0.64		1.35
2.7	3454	0.64		

source) is inserted into Monte Carlo generator. At the day, the Baksan and MACRO calculations have the same simulation scheme [26, 27] which applied the Bartol atmospheric  $\nu$  flux [28].

The second part means calculation of acceptance for the arrived muons with the same requirements for hardware triggers and the same set of a cuts as for real data for exclusion of those of neutrinos candidates which could be mimicked by particles produced by downward-going atmospheric muons with the large scattering angles or multiple muons (see [26, 27]).

There are a running routines of reproduce Cherenkov technique registration of relativistic neutrino-induced muons passing through a volum of pure water (the Super-Kamiokande) or natural water (the BAIKAL, the ANTARES project) or ice (the AMANDA) medium.

The detail description of installations are outside the scope of this paper, but for DM searching it is important to note a few characters of operating neutrino detectors and the obtained ratios of measured events to expected one.

## 4. Detectors: operating and running in progress

### 4.1. Scintillator detectors: BAKSAN and MACRO

Neutrino experiments at the Baksan telescope [29] under effective rock thickness of  $850\text{hg}/\text{cm}^2$  and at the MACRO [27] (3700 m.w.e. depth), are realized on basis of large scintillator detector and discrimination upward and downward-going muons by means of the time-of-flight method [30]. The MACRO detector have a few better parameters for a detection of muons from down hemisphere, first of all thanks to its strong reduction of background from the downward atmospheric muon flux, by factor of  $10^6$ . While the Baksan location is relevant to the  $5 \cdot 10^3$  reduction.

Trajectories of a penetrating particle at the Baksan are determined by the positions of hitted tanks, which put together a system of 3,150 liquid scintillator counters of standard type ( $70\text{cm} \times 70\text{cm} \times 30\text{cm}$ ) which entirely cover eight planes of fourfloor telescope's building ( $17\text{m} \times 17\text{m} \times 11\text{m}$ ). The configuration provides  $2^\circ$  of angular accuracy and the mean muon energy of about 20 GeV. The MACRO apparatus includes the system of around 20,000  $\text{m}^2$  of streamer tubes, that able to get a track's reconstruction within  $.5^\circ$ , although the angular accuracy gets worse for inclined tracks mainly contributed in the analysis of muons pointing in the direction of the Sun, due to installation's configuration ( $12 \times 76.6 \times 9\text{m}^3$ ).

The Baksan and the MACRO detectors are sensitive to searching for neutralinos with the masses from the lower limit [7]. That is because of theirs low energy threshold:  $E_{th}^\mu \approx 1\text{GeV}$  for vertical upward through-going muons. Presently, the both experiments have reached the same order of statistics, hence the results could be comparable.

During the Baksan observation from December 1978 until November 1998 the rejection of downward-going particles by hardware triggers left of about  $6,5 \cdot 10^6$  events, while the triggers provides 0.1% of the initial rate. Subsequent requirement of negative value of  $1/\beta$  around -1 (that relevants to upward-going particle) has selected 1056 events. There are additional cuts to a single track in order to exclude events mimicked by downward-going particles [11, 31]. The Baksan gave an evidence of 713 upward through-going muons with 14.8 years of live-time [31]. The last MACRO update [12] of  $\nu$ -events observation from March 1989 until February 1999 respects to 3.93 live-years in MACRO full configuration. Two different topologies of the MACRO detector [27] are used in the  $\nu$ -registration: upward through-going muons and internally produced upward-going particles, the energy range of latter one is close to  $E_{th}^\mu$ . Therefore, a sample of 642 upward through-going muons have been applied for searching for neutralinos from the Earth's core and 971 upward-going muons (including semi-contained events) are in case of the Sun.

Expectations at the Baksan from Monte Carlo simulations of atmospheric neutrinos (20 runs of live-time) in total number of events agree with measurements and in particular, there is consent in vertical bins within error bars, as it seen from Fig.2. The ratio of measured to expected events is found to be  $0.95 \pm 0.04(stat.) \pm 0.08(syst.) \pm 0.15(theor.)$ . The MACRO experiment has found a significant deficit of events in vertical bins in comparison with expectations from atmospheric neutrinos [27]. The pointed out ratio have been obtained to be  $0.740 \pm 0.031(stat.) \pm 0.044(syst.) \pm 0.12(theor.)$  [12].

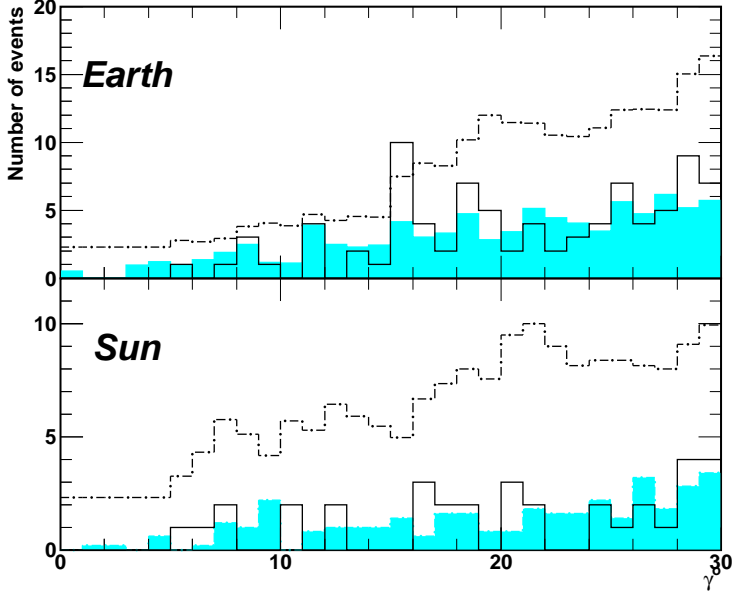
However, the fits of the shape of the experimental zenith angular distribution by the predicted one from the theory both with neutrino flavor oscillations and without one have a poor probabilities at the Baksan as well at the MACRO detectors [26, 25, 27, 12].

In the direction of the Sun both the Baksan and the MACRO experiments have concluded the absence of additional neutrino source relatively to the background evaluated from data itself [32, 11, 12]. The Baksan distribution of angles between the muon arrival direction and a radius-vector of the Sun is presented in Fig.2. There is a comparison with the measured background derived from data correlation with positions of fake 'suns' (points on the sky with the same acceptance as true Sun but shifted at some hour angles).

With the same order of statistics and similar defined energy thresholds the MACRO and the Baksan experiments have set a very close limits on muon fluxes at the 90% c.l. (see Tables 1 and 2). The angle ranges collecting 90% of neutralinos signal as a functions of its value of mass have been obtained with different SUSY models. Notice that the flux upper limits presented by the MACRO experiment does not connect here with found half-cones. The Baksan results have been derived [11] on the basis of phenomenological approach to MSSM and Monte Carlo simulations in studying of two detector dependent values: a muon detection probability per one neutralino pair annihilation both for the Earth and the Sun cases and a half-cones containing 90% of events. Therefore, the energy dependence of the detector acceptance on fall neutrino flux from different neutralinos has been accounted. Monte Carlo simulations have reproduced of 1,000 arrival muons from each set of neutralinos. The optimization of searching half-cones for neutralino signal at the MACRO detector has been done with SUSY models of Bottino et al.[23].

In determination of conservative limits on muon fluxes from the direction of the Earth's core, the MACRO has assumed equality between the number of measured events and the number of expected one after applied normalization separately to each of the considered search cones [12]: from  $3^\circ$  to  $30^\circ$ . The error of 5% has been estimated as maximum [12] with respect to accounting the dependence on energy of acceptance of the MACRO





**Figure 2.** Distribution in  $\gamma$  for upward-going muons from directions of the Earth's core and the Sun. Solid histogram is data and shaded one is expectation for atmospheric neutrinos. Dash-dotted histogram is upper limits at 90% c.l. on number of upward-going muons produced by neutrinos nonatmospheric origin as a function of cone opening angle  $\gamma$ .

detector with changing of neutrino energy spectra from different neutralino masses.

The obtained 90% c.l. flux limits as a function of neutralino mass have ruled out a considerable number of SUSY parameter space for the Sun as well as for the Earth, including one related with the interpretation of the DAMA/NaI data [35]. Notice that the MACRO determination of exclusion regions [12] assumed a rescaling of the mass density of the neutralino [23], which directly affects the capture rate, subsequently, muon flux value and hence, the conclusion on ruled out space.

The Baksan detector ability to probe MSSM parameter space has been shown previously in Ref.[32], where a large part of the space covering the resonance mass range for the Earth's capture [9] has been ruled at 90% c.l. as well as many SUSY models calculated by Gondolo et al.[22]. The recent analysis of Bergstrom et al. [33] with contribution from a new population of WIMPs coming from Galactic halo WIMPs [34] which could be scattered

in the outer layers of the Sun, has demonstrated a sizeable enhance the neutralino signal from the Earth. The conclusion is that many more models around 60-130 GeV previously thought to be allowed by Baksan but above the claimed DAMA bound [35] should really be considered as ruled out with even greater confidence.

#### 4.2. Cherenkov detectors: BAIKAL, AMANDA and ANTARES

The method of registration of Cherenkov light emitted by passing relativistic neutrino-induced muon in the large natural volume of water or ice is performed by a three-dimensional matrix of optical modules (OMs), which is deploying at the depth.

The pioneer realization of the BAIKAL running project in deployment of 72 m long strings supporting OMs at 1,100 m depth [16] and successful deployment of kilometer-long strings with OMs to 2300m depth at the South Pole by AMANDA collaboration [18] have provided observation of muons induced by very energetic muonic neutrino and thus, started the new generation of  $km^3$  detectors.

Both experiments have began in 1993 and have carried out a few season installations on basis of the complex programmes with monitoring of the properties of environment used for a particle detector and a lot of tests and calibrations in studying of transparency, radioactivity, the scattering length. The reduction of the biofouling deposited on the glass spheres with a time is the main care both at the Baikal and at a deep-sea running project of the ANTARES collaborations [19] started in the spring of 1996. Currently the ANTARES collaboration aims at building a  $0.1km^2$ -size detector made of 500 m long strings at 2350 m depth of Mediterranean sea by the end of 2000.

The operating large Cherenkov detectors have demonstrated that there is no up/down confusion of nearly vertical upgoing muons. Presently, the Baikal experiment has found 4 candidates survived all trigger cuts (energy threshold is order 10 GeV) with 70 live-days of NT-96 detector [15] which overlapping around  $1,000m^2$ . The 90% c.l. flux limits in the direction of the Earth's core [15] are present in Table 1. The AMANDA collaboration gave an evidence of 11 upward-going muons in angular window  $165^\circ$  with 85 days of AMANDA-B10 detector live-time from analysis of half of 1997 data sample [17]. They estimate that it can pinpoint the direction of a high-energy muon with an uncertainty of about  $3^\circ$ . The AMANDA preliminary statement is that [17, 18] both muon flux and angular distribution of upgoing events agree with expectations from Monte Carlo simulations of atmospheric neutrinos (three years of live-time) within error bars. For near vertical contained events an energy threshold might be estimated not much than 25 GeV. Upper limits on muon fluxes coming from the centre

of the Earth have been set at 90% c.l. for the neutralino mass range 100 GeV - 5 TeV with separation into soft and hard annihilation channels [17] (see summarized results in Table 1). This idea is a very fruitful, since the detector sensitivity is essentially improving due to adequate determination of the detector acceptance.

The measurement of the arrival time of the Cherenkov light by OMs means both a reconstruction of the muon direction and estimation of its energy. Due to optimization of the planning geometry of the ANTARES detector performed by Monte Carlo simulations [19] it has been inferred two energy different possibilities for the detection. First is measurement of fully contained muon tracks at the detector. Respective muon energy range would be 5-60 GeV that is suited for the neutrino oscillation study and the neutralino search. At higher muon energy ( $> TeV$ ) a precision of reconstruction of the energy spectrum gets worse into 2-3 times because of fluctuation of detected number of photons. In this case found geometry is relevant for study of the very high energy neutrino astronomical sources ( $> 100TeV$  at  $0.1km^2$ ) with a very good angular resolution: better  $0.2^\circ$  [19].

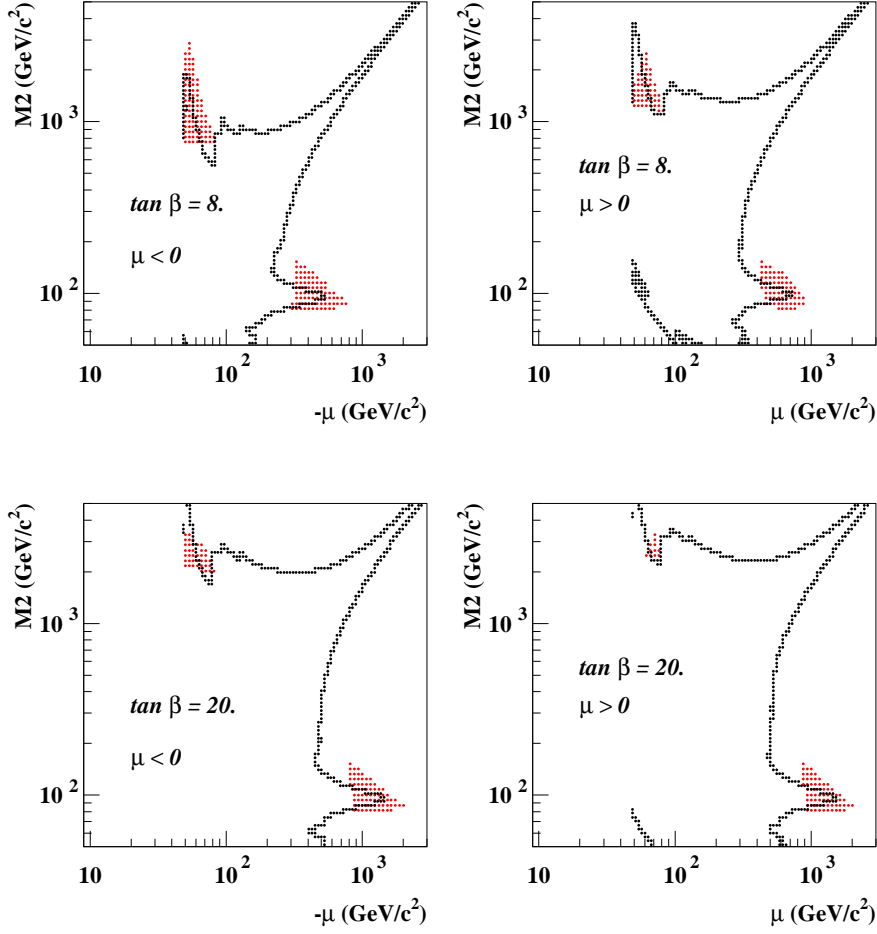
The case of ideal detector operating as a separate string of 500 m height with about 100 OMs grouped by floors to use only full contained events coming from nadir has been analyzed by F.Blondeau [20]. The expectation of 22 upgoing muons from atmospheric neutrinos has been obtained per one *string · year* exposition. Detector response to neutralino signal from the Earth core has been tested with Neutdriver code [2]. Obtained detector sensitivity around 60 GeV neutralino mass is seen in Fig.3 where the regions of MSSM parameter space allowed by the ANTARES detector [20] are shown in comparison with excluded counters from the Baksan [32].

## 5. Perspectives

The common perspective for the indirect searching for WIMPs in high energy neutrino experiments is connected with a quantity and a quality of measured statistics of muons coming from down hemisphere. There is also a dependence on technique of Monte Carlo simulations in complete reconstruction of neutrino signal accordingly to its origin. Finally, present uncertainties of astrophysical and nuclear parameters which determinate neutralino capture rates as well a priori unknown preferable region of space parameters could not give an unambiguous bound on mass and composition of neutralino even by planning detectors of upward-going muons.

Among the operating underground telescopes Super-Kamiokande [36] gives a very impressive results with high statistics confirming the zenith-angular-dependent deficit for contained events, to which atmospheric neutrinos in the 0.1-10 GeV energy range are relevant. Having in mind the

## *Comparison with Baksan*



**Figure 3.** The ANTARES allowed regions together with excluded one by the Baksan limits on the upward-going muons at the 90% c.l.

last update of upward through-going muons with 1021 data sample per 923 days [36] corresponding to  $E_{th}$  order 7 GeV, the expected signal from the neutralino with masses covered resonance range for the Earth could be tested. The recognition of neutrino flavor oscillations would play a crucial role, since this process could decrease the expected neutralino signal considerably (by factor 0.5-0.8 for neutralino mass less 100 GeV) as it has been shown by Fornengo [37]. Notice that there is a  $\tau$ -lepton channel in the neutralino annihilations which offers a generation of  $\nu_\tau$  in decay chain and a hard spectrum of  $\nu_\mu$ .

In perspective one may wait both the resolving of the measured deficit of nearly vertical upward-going muons at the MACRO detector and determination more precisely the influence of instability of the detector parameters during long term operation of the Baksan telescope, since the obtained systematic uncertainties are too large (8%). The data of the Baksan and the MACRO with relatively low energy threshold (1 GeV) could be used to set a separate limits on soft and hard neutrino fluxes and as to be compared with accelerator limits in SUSY parameter space.

The running projects of new generation of neutrino telescopes imply a kilometer sizes, but with larger effective area they will have also higher energy threshold and thus, could lose a sensitivity to the neutralino mass range (50-100 GeV) where is expected a resonance WIMP capture in the Earth. The detail discussion of trade-off between area and energy threshold for indirect search for dark matter by km-size detector are presented in Ref.[22]. The method using full contained events coming near nadir at the ANTARES project developed for neutrino oscillation study is predicted to detect a signal from neutralinos with a mass close to 60 GeV.

## 6. In conclusion

The operating neutrino telescopes did not gave an evidence for additional sources of high energy neutrinos from the centre of the Earth as well from the Sun, and the 90% c.l. limits on upward-going muons fluxes are setten.

The indirect method of searching for WIMP signal directly depends on value of uncertainties both measurements and theory, the decreasing of which is too complicate task. The optimization of the ratio of expected neutralino signal to background from atmospheric neutrinos is the applied way in searching for dark matter WIMPs. There is a complementarity of the low and high energy threshold detectors which are sensitive to a different neutralino mass range.

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